

Natural Alternative Hosts of Eulophidae (Hymenoptera: Chalcidoidea) Parasitoids of the Citrus Leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) in the Mediterranean Basin

BRUNO MASSA, MARIA CONCETTA RIZZO, AND VIRGILIO CALECA

Istituto di Entomologia agraria, Università degli Studi di Palermo, Viale delle Scienze 13,
90128 Palermo, Italy. E-mail: zoolapp@unipa.it

Abstract.—The entomofauna linked to native flora in and around citrus groves was studied in Italy and Jordan in order to find alternative hosts of eulophid parasitoids of the Citrus Leafminer (CLM), *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae). Twenty new associations (12 in Italy, 8 in Jordan) among native and exotic CLM parasitoids and leafminers were found. Two new alternative hosts were recorded for *Citrostichus phyllocnistoides* (Narayanan) (an unidentified Nepticulidae on *Pistacia lentiscus* L. and *Stigmella* sp. on *Rubus ulmifolius* Schott, in Sicily and Jordan respectively) and 1 for *Cirrospilus ingenuus* Gahan (Agromyzidae on *Salix* sp., in Jordan). Five new alternative hosts were recorded for *Semielacher petiolatus* (Girault) (in Sicily *Liriomyza* sp. on *Mercurialis annua* L., *Chromatomyia horticola* (Goureau) on *Sonchus* spp., *Cosmopterix pulchrinella* Chambers on *Parietaria diffusa* M. et K., and *Stigmella aurella* (Fabr.) on *Rubus ulmifolius* Schott; in Jordan, *Dialectica scalariella* Zeller on *Echium* sp.). The other 12 new associations of CLM parasitoids with leafminers found in both countries include *Neochrysocharis formosa* (Westwood) (4 new hosts), *Cirrospilus variegatus* (Masi) (5 new hosts), *Ratzeburgiola incompleta* Bouček (1 new host), *Ratzeburgiola cristata* (Ratzeburg) (1 new host), and *Asecodes delucchii* (Bouček) (1 new host). Data reported here suggest that native vegetation harbours alternative hosts for both native and exotic parasitoids. They also underline that more attention should be paid to the understanding of ecology and biology of parasitoid species in order to use appropriate exotic enemies in biological control, preserving at the same time indigenous parasitoid communities.

The Citrus Leafminer (CLM), *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae), is presently considered to be a serious threat to young citrus trees in the Mediterranean region and other countries, where it has expanded its range in the last seven years. The CLM attacks new leaves causing a loss of photosynthetic area. *Semielacher petiolatus* (Girault), *Citrostichus phyllocnistoides* (Narayanan) and *Cirrospilus ingenuus* Gahan (Hymenoptera: Eulophidae) are considered among dominant natural enemies of CLM in its original range (India and South Asia) and in Australia (Smith *et al.* 1997, Schauff *et al.* 1998). Eulophid parasitoids have been selected for biological control programmes against

CLM in many countries and in some case also have been recovered in neighbouring countries (Schauff *et al.* 1998).

Native plants are an important source of biological diversity in agroecosystems and are known to harbour natural enemies of phytophagous pests of cultivated plants, supplying alternative food, refuges and hosts (McMurtry and Johnson 1965, Powell 1986, Altieri 1991, Ragusa Di Chiara 1991). They provide a diverse source of food for many species of polyphagous natural enemies, which in turn may parasitize phytophagous insects of cultivated plants in seasons when they are abundant.

Studies of phytophagous insects are often directed at species attacking cultivated

plants and, less so, species feeding on native ones; thus our knowledge of the hosts of parasitoids on cultivated plants is extensive, whereas we have only scattered data on the alternative hosts available to these parasitoids on native plants. Preservation of these reservoirs of antagonists may prove valuable when parasitoids utilize hosts that are not pests of cultivated plants, and when biological control depends on multiple natural enemy species, as in the case of the CLM.

The present study is part of a research project examining the entomofauna of native flora carried out in 11 citrus orchards of Sicily (Italy), the results of which were partly published (Caleca *et al.* 1997, Mineo *et al.* 1997a, 1997b, Caleca 1998, Caleca *et al.* 1998, Mineo and Sinacori 1998, Rizzo *et al.* 1999, Massa and Rizzo 2000). Some new findings are presented that highlight interesting relationships between CLM parasitoids and their non-pest hosts exploiting native plants.

MATERIALS AND METHODS

Native floras associated with citrus groves in Sicily (Italy) have been studied in detail by Raimondo *et al.* (1979); they amount to about 200 species involving mainly herbs and shrubs. During the four years of our research project (1997–2000), we collected about 40 of the most common species belonging to this flora, and about 10 belonging to riverine flora sometimes occurring in the neighbouring areas of citrus orchards in Sicily. About 250 g of each plant species were collected monthly along at least two perpendicular transects inside 11 citrus groves and along their perimeter. Leaves infested by miners were placed in Petri dishes with wet paper at 25° C, 65% r.h. and L14:D10. All phytophagous species and parasitoids that emerged were mounted and identified. Further samples were gathered by the senior author during a research trip to Jordan between 21 and 29 May 1999 in the

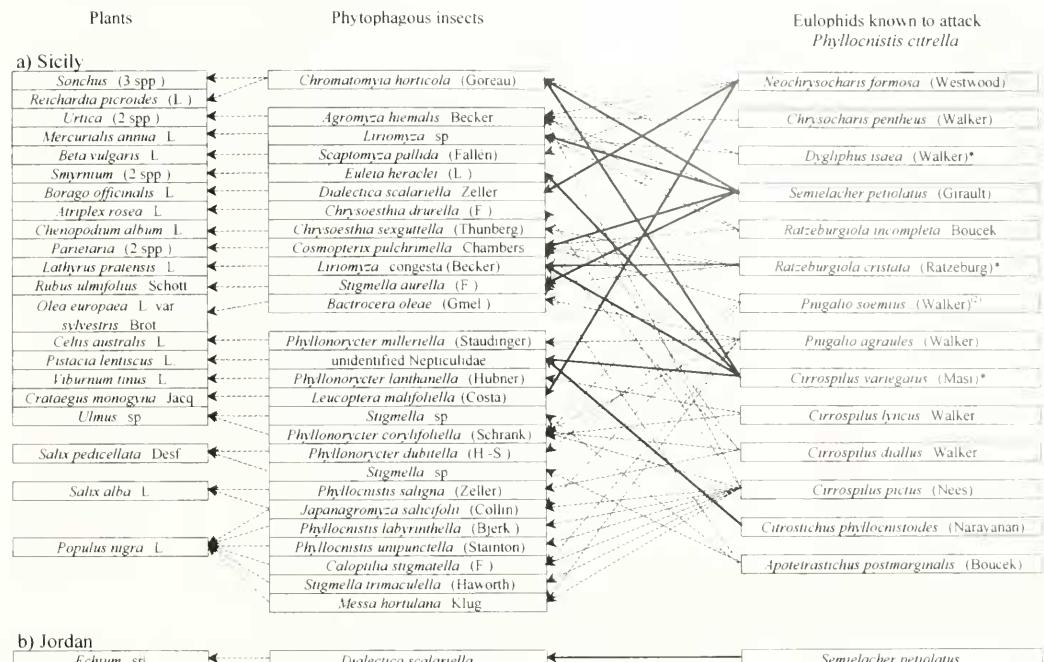
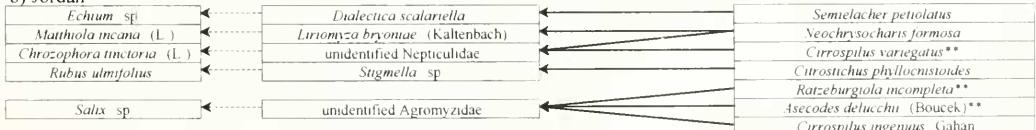
following localities: Al Bahhath (Amman), Aqaba and Dana Village.

RESULTS

In Sicily, 40 host-parasitoid associations involving phytophages of native plants and antagonists of CLM were already known (Caleca *et al.* 1997, Mineo *et al.* 1997a, 1997b, Caleca 1998, Caleca *et al.* 1998, Mineo and Sinacori 1998, Rizzo *et al.* 1999, Massa and Rizzo 2000). They are listed in Fig. 1 together with the 12 (Italy) and 8 (Jordan) associations, previously unnoticed, recorded in the present paper. Data for new records are reported in Table 1.

The parasitoids we found on indigenous leafminers belong to two quite different kinds: exotic CLM biological control agents (i.e., *Semielacher petiolatus*, *Citrostichus phylloconistoides* and *Cirrospilus ingenuus*), which possibly have switched over onto indigenous hosts after their introduction or immigration, and native parasitoids, which in turn have switched over onto the invading CLM. Among the latter, some (i.e., *Neochrysocharis formosa* (Westwood), *Ratzeburgiola incompleta* Bouček and *Pnigalio soemius* (Walker)) are quite common on indigenous hosts in Sicily (Fig. 1a), while three of them (i.e., *Diglyphus isaea* (Walker), *Ratzeburgiola cristata* (Ratzeburg) and *Cirrospilus variegatus* (Masi)) have not yet been recorded on CLM in the island, although they have been reported on this host in other countries (Schauff *et al.* 1998). It should be pointed out that, even if their parasitization does not always reach relevant values, most CLM parasitoids engage in host-feeding which contributes additional mortality. For example in Algeria Guenaoui and Dahliz (1997) attributed as much as 20–50% of CLM larval mortality to host-feeding and in Sicily it may approach 15% (pers. obs.).

Among the eight new host-parasitoid associations reported from Jordan (Fig. 1b), five concern eulophids (*S. petiolatus*, *N. formosa*, *C. phylloconistoides* and *C. ingenuus*)

**b) Jordan**

← New records

↔ Known records, parasitoid-host relationships after Caleca et al. 1997, Caleca 1998, Caleca & Lo Verde 1998, Caleca et al. 1998, Mineo et al. 1997a, b, Mineo & Sinaori 1998, Rizzo et al. 1999, Massa & Rizzo (2000)

• Species recorded in other Mediterranean areas on *P. citrella*, but unrecorded on this host in Sicily** Species recorded in other Mediterranean areas on *P. citrella*, but unrecorded on this host in Jordan† This species was recorded by Caleca et al. (1997) on *Beta vulgaris* ex *Scaptomyza* sp., after collecting new material this host has been identified as *Scaptomyza pallida*‡ This species was recorded by Caleca (1998) on *Salix alba* ex unidentified Agromyzidae, after collecting new material this host has been identified as *Japanagromyza sahicifolia*

Fig. 1. Associations between euplophid parasitoids of *Phyllocnistis citrella* and other phytophagous insects exploiting native plants in Sicily (a) and Jordan (b).

known to attack CLM in the country (Schauff et al. 1998, Mineo 1999). *C. variegatus*, *R. incompleta* and *A. delucchii* (Bouček) have been recorded as CLM parasitoids in other countries of the Mediterranean Basin, but until now have been found only on native plants in Jordan, although this may be due to the paucity of information on CLM in this country. Some details on the new findings are reported below.

Semielacher petiolatus (Girault)

Originally described from Australia, *S. petiolatus* has also been reported from the

Solomon Islands (Bouček 1988, Schauff et al. 1998). It was introduced to Oman, Syria, Israel, Egypt, Cyprus, Greece, Turkey, Tunisia and Morocco (Michelakis 1997, Argov and Rössler 1996, FAO 1996, Nia et al. 1997, Rössler and Argov 1997, Hamed et al. 1999); it spread spontaneously in Italy, Algeria and Jordan (Mineo et al. 1998, Schauff et al. 1998, Mineo 1999). Before being reared from *Agromyza hiemalis* Becker (Diptera: Agromyzidae) (Massa and Rizzo 2000), the only host previously known for this species was the CLM (Schauff et al. 1998), and, from 1998 onwards, it became one of the most important parasitoids of

this pest in Sicily (Caleca *et al.* 1998, Mineo and Mineo 1999a). The five new hosts listed in this paper (Table 1), comprising three Lepidoptera (Cosmopterigidae, Nepticulidae and Gracillariidae) and two Diptera (Agromyzidae), are widespread in the Mediterranean region.

It should be noted that this species appeared in Sicily on *Chromatomyia horticola* (Goureau) (Diptera: Agromyzidae) about one year after its release in 1996 in Tunisia (FAO 1996). The availability of alternative hosts that provide refuge and food for *S. petiolatus* during seasons of low CLM population density, could partly explain the quick spread and establishment of this species, both in countries where it has been released and in neighbouring sites (Caleca *et al.* 1998, Schauff *et al.* 1998, Mineo and Mineo 1999a).

Citrostichus phyllocnistoides (Narayanan)

This species is known from Afghanistan, China, India, Indonesia, Japan, Oman, Pakistan, Taiwan, Thailand, South Africa, Sudan, Swaziland (Bouček 1988, FAO 1996, Schauff *et al.* 1998), and has been introduced to Cyprus, Greece and Italy (Sicily) (Michelakis 1997, FAO 1996, Mineo and Mineo 1999b), and Australia and Israel (where it is not considered established) (Smith *et al.* 1997, Argov and Rössler 1996). It probably spread to Jordan from Israel (Mineo 1999). Although recorded as a parasitoid of the CLM (Bouček 1988, Ujiye and Adachi 1995, Wu and Lin 1998), it also has been reported to parasitize the nymphs of *Trioza obsoleta* Buckton (Homoptera: Psyllidae) a gall former on *Diospyros melanoxylon* (Roxb.) (Dash and Das 1997). Our records concern two additional Lepidoptera (Table 1); according to Nieuwerken (pers. comm.) the mines on *Rubus ulmifolius* Schott found in Jordan belong to a *Stigmella* species (Nepticulidae), possibly *Stigmella aurella* (Fabr.), a previously unrecorded host for this parasitoid.

Cirrospilus ingenuus Gahan

Also known as its synonym *C. quadristratus* (Subba Rao and Ramamani), this species has been recorded from Australia, China, India, Indonesia, Japan, Malaysia, Oman, Taiwan, Thailand (Smith *et al.* 1997, Schauff *et al.* 1998), and introduced to Cyprus, Turkey, Israel, Syria, Egypt, Tunisia, Morocco, Florida and Mexico (Argov and Rössler 1996, FAO 1996, Perales-Gutierrez *et al.* 1996, Hamid *et al.* 1999, LaSalle *et al.* 1999). It has also spread to Jordan and North Egypt, probably from other countries of the Mediterranean Basin (Schauff *et al.* 1998). It is generally considered to be a dominant parasitoid of *P. citrella* (e.g., Thailand, Taiwan and Japan: Ujiye *et al.* 1996), but also has been recorded as a parasitoid of *Rhynchaenus mangiferae* Marshall (Coleoptera: Curculionidae) in India (Peter and Balasubramanian 1984). Agromyzidae previously has not been recorded as a host for this parasitoid.

Cirrospilus variegatus (Masi)

Also known as its synonym *Zagrammosoma variegatum*, it occurs in the Mediterranean Region, North and East Africa, Central and South Asia, West Indies (Barbados), Australia and New Zealand (Bouček 1988; Yefremova 1996). This species was described from Italy by Masi (1907), as parasitoid of *Metriochroa latifoliella* (Millière) (Lepidoptera: Gracillariidae). It is also known to parasitize many species of small leaf-mining Lepidoptera (Bouček 1988, Yefremova 1996) and the CLM in Libya, Spain and Turkey (Schauff *et al.* 1998). During this study it was found on two Nepticulidae leafminers and on three Diptera (one Tephritidae and two Agromyzidae) (Table 1), all previously unrecognised as hosts.

Ratzeburgiola incompleta Bouček

Recorded from central Europe and many countries of the Mediterranean Ba-

Table 1. List of new host records for Eulophidae emerged from leafminers reared from native plants collected in Italy and Jordan.

Eulophid	Host species	Host plant	Data	Sex
<i>Semielacher petiolatus</i> (Girault)	<i>Chromatomyia horticola</i> (Goureau) (Diptera: Agromyzidae) <i>Liriomyza</i> sp. (Diptera: Agromyzidae) <i>Cosmopterix pulchrinella</i> la Chambers (Lepi- doptera: Cosmopter- igidae)	<i>Sonchus</i> spp. <i>Mercurialis annua</i> L. <i>Parietaria diffusa</i> M. and K.	Italy, Parco d'Orléans (Palermo) 3.V.97, 21.III.99 Italy, Borgo Molara (Palermo) 29.XI.98 Italy, Zucco (Palermo) 6.VI.00, Borgo Mo- lara 26.I.99, 14.III.99	2♂
	<i>Stigmella aurella</i> (Fabr.) (Lepidoptera: Nepti- culidae) <i>Dialectica scalariella</i> Zeller (Lepidoptera: Gracillariidae)	<i>Rubus ulmifolius</i> Schott <i>Echium</i> sp.	Borgo Molara 17.VIII.99, Parco d'Orléans 20.IX.99 Jordan, Dana Village 25.V.99	1♀
<i>Citrostichus phyllocnisto- ides</i> (Narayanan)	Lepidoptera: Nepticu- lidae	<i>Pistacia lentiscus</i> L.	Zucco 4.IV.00	1♂, 1♀
	<i>Stigmella</i> sp. (Lepidop- tera: Nepticulidae)	<i>R. ulmifolius</i>	Jordan, Al Bahhath (Amman) 23.V.99	1♂, 1♀
<i>Cirospilus ingenuus</i> Gahan	Diptera: Agromyzidae	<i>Salix</i> sp.	Al Bahhath 23.V.99	1♀
<i>Cirospilus variegatus</i> (Masi)	<i>C. horticola</i>	<i>Reichardia picroides</i> (L.)	Italy, Collesano (Paler- mo) 20.V.99	1♀
	<i>Liriomyza congesta</i> (Becker) (Diptera: Agromyzidae)	<i>Lathyrus pratensis</i> L.	Collesano 20.V.99	1♀
	<i>Eulcia heraclei</i> (L.) (Diptera: Tephritis- idae)	<i>Smyrnium perfoliatum</i> (L.)	Italy, Petralia Sottana (Palermo) 6.VI.99	3♀
	Lepidoptera: Nepticu- lidae	<i>P. lentiscus</i>	Zucco 27.VIII.99	1♂
	Lepidoptera: Nepticu- lidae	<i>Chrozophora tinctoria</i> (L.)	Jordan, Aqaba 27.V.99	3♂, 4♀
<i>Ratzburgiola incompleta</i> Bouček	Diptera: Agromyzidae	<i>Salix</i> sp.	Al Bahhath 23.V.99	1♂
<i>Ratzburgiola cristata</i> (Ratzeburg)	<i>L. congesta</i>	<i>L. pratensis</i>	Collesano 20.V.99	2♀
<i>Neochrysocharis formosa</i> (Westwood)	<i>D. scalariella</i>	<i>Borago officinalis</i> L.	Italy, Bagheria (Paler- mo) 20.XI.97	1♀
	<i>Leucoptera malifoliella</i> (Costa) (Lepidop- tera: Gracillariidae)	<i>Crataegus monogyna</i> Jacq.	Zucco 7.VIII.99	7♀
	<i>Liriomyza bryoniae</i> (Kaltenbach)	<i>Matthiola incana</i> (L.)	Al Bahhath 23.V.99	1♂, 2♀
	Lepidoptera: Nepticu- lidae	<i>C. tinctoria</i>	Aqaba 27.V.99	2♂, 1♀
<i>Asecodes delucchii</i> (Bouček)	Diptera: Agromyzidae	<i>Salix</i> sp.	Al Bahhath 23.V.99	1♀

sin (Bouček 1969, 1970, Schauff *et al.* 1998), this species is known to parasitize *Holocacista rivillei* Stainton (Lepidoptera: Heliozelidae) (Bouček, 1969), *Phyllonorycter corylifoliella* Hübner (Lepidoptera: Gracillariidae) (Mineo and Sinacori 1998), *Cosmopterix pulchrimella* Chambers (Lepidoptera: Cosmopterigidae) (Rizzo and Mineo 1997), *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae) (Freidberg and Gijswilt 1983), *Liriomyza* sp. (Diptera: Agromyzidae) (Rizzo and Mineo 1997), and *Agromyza hiemalis* (Massa and Rizzo 2000). It is also recorded as CLM parasitoid (Azawi 1997, Schauff *et al.* 1998), and as the most abundant native CLM parasitoid in Turkey (Uygun *et al.* 1997) and Israel (Rössler and Argov 1997).

Ratzeburgiola cristata (Ratzeburg)

Known from the whole Europe (Bouček and Askew 1968, Rizzo and Mineo 1997, Schauff *et al.* 1998) parasitizing *Phyllonorycter nigrescentella* Logan (Lepidoptera: Gracillariidae) and *Cosmia trapezina* L. (Lepidoptera: Noctuidae) (Bouček and Askew 1968), *Chrysoesthia sexguttella* (Thunberg) (Lepidoptera: Gelechiidae), *Cosmopterix pulchrimella* and *Stigmella aurella* (Rizzo and Mineo 1997), and the CLM in Spain (Schauff *et al.* 1998). Agromyzidae previously has not been recorded as a host for this parasitoid.

Neochrysocharis formosa (Westwood)

This species is known from the Palearctic, Asia and Africa (Bouček and Askew 1968). It develops as a primary endoparasitoid of larvae, and rarely eggs, of leaf-miners (Hansson 1990), and is known as parasitoid of *P. citrella* in Cyprus, Greece, Israel, Italy, Japan, Jordan, Spain, Tunisia and Turkey (Caleca *et al.* 1996, FAO 1996, Ujiye *et al.* 1996, Schauff *et al.* 1998).

Asecodes delucchii (Bouček)

Asecodes delucchii (= *Teleopterus delucchii*) is known throughout the Palearctic Region from England to Japan (J. LaSalle,

pers. comm.), but has not been previously recorded in Jordan. It is known to attack *P. citrella* in Italy and Japan (Ujiye and Adachi 1995, Ujiye *et al.* 1996, Mineo 1999), and has also been recorded as a parasitoid of *Caliroa cerasi* L. (Hymenoptera: Tenthredinidae) and *Phyllonorycter messanella* (Zeller) (Lepidoptera: Gracillariidae) (J. LaSalle, pers. comm.). Agromyzidae previously has not been recorded as a host for this parasitoid.

DISCUSSION

The introduction of exotic polyphagous parasitoids could decrease native parasitoids competing for the same food resource (Bennett 1993, Duan *et al.* 1996); thus, due to the naturally low density of their populations, native polyphagous parasitoids may undergo dramatic decrease to become locally extinct (LaSalle 1993). For these reasons, to find the best control agent of a noxious insect before using it in biological control programs LaSalle (1993) suggested carrying out research on the biology and ecology of species of parasitoids that are considered antagonists of the host.

Since 1993, when *P. citrella* colonised Mediterranean citrus groves, endemic biological diversity represented the potential resource for biological control (cf. LaSalle 1993). A dozen native polyphagous eupophids were found to parasite it. These species constituted the parasitoid community living on leaf-miners of the native flora. Research carried out in Sicily listed a total of 47 associations involving native eupophids that parasitize the CLM (Caleca *et al.* 1997, Mineo *et al.* 1997a, 1997b, Caleca 1998, Caleca *et al.* 1998, Mineo and Sinacori 1998, Rizzo *et al.* 1999, Massa and Rizzo 2000, present study) (cf. Fig. 1a). Among CLM parasitoids, the genus *Cirrospilus* (Hymenoptera: Eulophidae) played a dominant role, particularly *C. pictus* (Nees) in Sicily, Algeria and Spain (Caleca *et al.* 1998, Guenaoui and Dahlis 1997, Vercher *et al.* 1997). Due to

the spread of CLM, many researchers planned the introduction of its specific control agents; in the Mediterranean Basin today at least 6 exotic species, known as dominant parasitoids of *P. citrella*, have been introduced (Argov and Rössler 1996). Among them *S. petiolatus* spontaneously colonised Sicily (Mineo *et al.* 1998), probably from N Africa, where it had been introduced, while *Ageniaspis citricola* Logvinovskaya (Hymenoptera: Encyrtidae) and the eupophids *Quadrastichus* sp. and *C. phyllocnistoides* were here actively introduced (Siscaro *et al.* 1997, Mineo and Mineo 1999b).

Our research led us to find 5 alternative new native hosts of *S. petiolatus* and 2 of *C. phyllocnistoides*, as well as another new host of *C. ingenuus*, eupophids previously known as dominant or specialist CLM parasitoids. We believe that alternative hosts, leaf-miners of native flora, contributed to acclimatation of *S. petiolatus* and *C. phyllocnistoides* in Sicily, providing alternative food and shelter, mainly in winter and spring, when CLM populations decrease very much (Massa and Rizzo in press). As regards the interference determined on native CLM parasitoids by exotic ones, *S. petiolatus* in 1998 represented as much as 38% of all the parasitoids in an orange grove, with an average parasitization rate of 6.9%, peaking to 87.5% in September (Caleca *et al.* 1998), while in 1999 it represented 89% of all the parasitoids in a lemon grove, with a peak of parasitization rate of 69.6% (Mineo and Mineo 1999b), playing a dominant role in the CLM control. *C. phyllocnistoides* on the contrary seems to be still sporadic in Sicily (Mineo and Mineo 1999b).

Among native CLM parasitoids in Sicily, in 1998 *C. pictus* reached 7.9% of parasitization rate, while all the other parasitoids did not exceed 2% (Caleca *et al.* 1998), values already known before the introduction of exotic parasitoids. As regards the parasitization on hosts of native flora, even if our data do not present a

significant quantitative analysis, from the qualitative point of view it seems that the community structure of parasitoids did not change after the introduction of exotic species (Caleca *et al.* 1997, Mineo *et al.* 1997a, 1997b, Caleca 1998, Caleca *et al.* 1998, Mineo and Sinacori 1998, Rizzo *et al.* 1999, Massa and Rizzo 2000). The number of individuals of *S. petiolatus* and *C. phyllocnistoides* found parasitizing native hosts indeed is still low, compared with the whole number of parasitoids (564) obtained during our research (Massa and Rizzo in press).

Finally, our results point out that native flora within and at the edge of citrus groves strengthens the biological control of *P. citrella*, providing alternative hosts to its parasitoids, native as well exotic, mainly in the winter-spring seasons when *P. citrella* density is very low. Additionally, they stress the importance of knowledge of parasitoid biology and ecology to optimise their use in biological control programs, as well the conservation of native parasitoid communities.

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